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PRINCIPLES OF PALEONTOLOGIC CORRELATION.[1]

CONTENTS

General discussion.—Geologic correlation has been carried on ever since the pupils of Werner endeavored to recognize his stratigraphic divisions in remote parts of the earth; and since William Smith discovered that fossils are characteristic of certain formations, paleontologic correlation has been attempted. Still it must not be forgotten that the greater part of the correlation that has been done up to this time is based on lithologic and stratigraphic rather than on faunal data. Fossils have been regarded as incidental, useful in recognizing strata, but not as a basis for subdivisions on account of changes in fauna or flora.

Where a rock-bed of distinctive character is persistent over a wide extent of country, a lithologic correlation would reach as good, and often even better, results than could be obtained from

[1] Read before Section E. Amer. Assoc. Adv. Sci., June 28, 1900.

paleontologic data. But outcrops of strata are deceptive, and often apparently continuous beds of the same character turn out to contain a number of different formations. In the western states such lithologic and stratigraphic correlations have been, more often than not, erroneous, while in the Mississippi valley region they have usually been at least approximately correct, because the great geologic events that were the causes of the stratigraphic changes were uniform over wide areas. Even today the catastrophe doctrine of Cuvier makes itself felt, and we find paleontologists and stratigraphers using unconformities as a basis for the separation of Cretaceous from Jurassic, where the fossils do not tell a definite story, as if the uplift and erosion would necessarily come at the same time in Europe and America.

Paleontologic correlation itself is not infallible; it must be used intelligently, its sources of error known and guarded against, or else it is little more reliable than the lithologic method; these errors lie chiefly in defective knowledge of the vertical and horizontal range of species or genera chosen as criteria, and in erroneous identification of these forms. Careful collecting, accurate field and laboratory discrimination, and wide knowledge of the literature are the best safeguards.

Two sorts of paleontologic correlation may be recognized, the direct, and the indirect method. In a limited province, such as existed in England and France during Cretaceous time, faunas were distributed uniformly over the area and had the same range in the two countries. Thus correlation of English and French Cretaceous strata is simple and direct, for they represent sediments that were once continuous, that were laid down in the same basins or along the same margins, under the same climatic conditions, and contained the remains of a similar fauna.

On a larger scale the problem of correlating the western European Cretaceous beds with those of the Atlantic slope Cretaceous of North America is the same. These strata were all deposited in the same faunal region, and although there are provincial differences the American and the western European faunas are remarkably similar, with even many species in common to

the two provinces, and most of the genera. During Cretaceous time there must have been easy intercommunication between Europe and America by a submerged continental shelf, keeping well within the temperate conditions. This state of things persisted through the Eocene, for the same similarity of faunas has been noted on the two continents in strata of that period.

On a still larger scale the same sort of correlation has been carried out between the western American and the Alpine Upper Trias, where many of the species and nearly all the genera are common to the two localities, although they are not in the same province, nor even in the same faunal region, and separated by six thousand miles in a direct line, and by at least twelve thousand miles by the nearest direction in which migration could have taken place. Yet there must have been easy intercommunication by continental margins from the American region, through the Oriental, to the Mediterranean region, along the borders of the ancient Mesozoic "Tethys" or central Mediterranean sea, that stretched eastward from the Alpine province through Asia Minor, India, and at least to the borders of China and Japan.

Direct correlation is possible even where there is no community of species, if a number of characteristic short-lived genera be common to the two regions. Thus the student of stratigraphic paleontology has no difficulty in correlating the *Meekoceras* beds of the Lower Trias, whether they occur in the Himalayas, Siberia, California, or Idaho; the fauna is essentially similar in all these regions, although species common to them are not yet identified. These faunas must have had a common origin either in one of these regions or in some unknown outside region, and reached the American and Asiatic provinces by migration. The place of origin may have been distant enough for the migrant faunas to have become specifically differentiated by the time they had reached their distant goals. In fact this is probably by far the more common case. Absolute specific identity between regions as distant as Asia and America must be rare; in reality there are usually in common to such regions only what

are called "representative species." This is especially true in a time of quiet development, where the fauna is largely endemic, and where there was no chance for outside elements to get into the region.

Indirect correlation also may be of two kinds; the first of these is where no fossils of extra-regional distribution are known in a formation, but where the formations above and below can be recognized. An example of this is the classification of the Algonkian system or its equivalents; the clastic pre-Cambrian, and post-Archean sediments all over the world are placed in this division, although no fauna that is characteristic is known in them as yet. Such correlation can only be tentative or preliminary, as is the present classification of the Newark formation of the Atlantic coast.

The second sort of indirect correlation is where no fossils are common to two separated regions, but elements of both are found together in a third region. A good example of this is the correlation of the Cretaceous strata of the west coast of North America with those of the interior and the Atlantic region, During the greater part of Cretaceous time the two regions were separated by a land mass so that their faunas were totally distinct, not only the species but even the genera being different. And these difficulties are seen in the attempts of the earlier stratigraphers to assign the various formations to their proper places. But when the Indian Cretaceous fauna was described, it was seen at once that there were striking analogies between that and genera and species of California. And since the Indian formation was accurately correlated with the Cretaceous of Europe, it became comparatively easy to assign the Californian strata to their proper place by this indirect comparison with the European standard. The Cretaceous of the Atlantic region had long before this been correlated with European, and thus the formations of the Atlantic region and of the Pacific coast were finally placed in harmony through the medium of comparison with a region thousands of miles from either.

Paleontologic zones.—Ever since William Smith demonstrated

that the various beds of the English Jurassic may be recognized by their fossils, the stratigraphy and paleontology of this formation have been a favorite field for investigation. Jurassic strata with abundant marine fossils are widely distributed in England, France, Germany, and Switzerland, in easy reach of universities and museums, so that the student of these faunas has an unusual wealth of material at hand. And in this western European province comparatively uniform conditions prevailed during the greater part of this time, allowing the faunas to become widely distributed. It is doubtful if any other succession of fossil faunas in the world is so well known as that of the Jurassic of this province, or if anywhere else such minute stratigraphic and faunal division has been successfully carried out; for there is not a single bed in all the great thickness of Jurassic sediments that does not contain somewhere in this province a rich marine fauna.

Quenstedt devoted his life to a minute subdivision of the Jurassic of Württemberg, establishing a classification that still holds sway in Germany; but this classification was based on local faunas, whose appearance and disappearance were caused by insignificant local changes in sedimentation, and it could hardly be used away from the place where it originated. In this scheme the greater unconformities, overlaps, and faunal changes received no more attention than the smaller geologic events. It was, then, merely a useful local classification, although of great value as a starting point in comparative study.

It was reserved for Albert Oppel,[1] a pupil of Quenstedt, to establish a chronological classification, based entirely on paleontology, and independent of lithologic development. For the entire Jurassic formation Oppel recognized thirty-three zones, or subdivisions characterized by certain species that occurred only in these horizons. The species chosen were of the greatest horizontal and the least vertical distribution, and were usually ammonites. These zones were thought by Oppel to be universal, for he was able to recognize them in Germany, Switzerland,

[1] Die Jura Formation, 1856.

France, and England, and by means of them was able to bring into harmony the local subdivisions already established in these various countries.

This was an important step in the right direction, but experience has shown, since Oppel's time, that these zones were not universal, and could seldom be recognized outside of the province where they were established — not even there always, when there was much difference of facies. So this scheme failed of its immediate purpose, although the final results of it have been more important than Oppel probably ever anticipated.

A further application and enlargement of Oppel's plan has been attempted by Buckman,[1] who has divided the Jurassic formation into *hemerae*, based on the occurrence of certain characteristic species of ammonites. An *hemera* represents a time considerably shorter than a zone, for the Lias, or Lower Jura, alone is divided into twenty-six *hemerae*. These are undoubtedly of much use to the stratigraphic paleontologist in England, probably in France, and possibly in Germany; but these *hemerae* can not possibly be identified away from the limited province where they were established, for in the Alpine or the Austrian Jura one is often lucky to be able to tell whether certain beds belong to Lower, Middle, or Upper Jura. Such finely drawn subdivision is of use only in local stratigraphy.

Buckman further classed a number of *hemerae* together in *ages*, based on the development of a group or series of species; in the Lias alone there are four of these *ages*, which correspond more nearly to the zones of Oppel, but even these could hardly be recognized in southern Europe, and much less in Asia or America.

Oppel thought that his zones were universal, or interregional, but only occasionally can one of them be identified outside of the province where it was named. This is due to the distribution of certain characteristic fossils outside of their usual range, on account of conditions temporarily facilitating interregional

[1] Quart. Jour. Geol. Soc. London. Vol. LIV, 1898. On the Grouping of some Divisions of so-called Jurassic Time.

migrations, which can occur only at times of readjustment of faunal provinces. There can be none in the intermediate periods of stability and quiescence when the fauna is endemic.

The writer proposes to retain the term "zone," in the sense intended by Oppel, as a chronologic term for a limited horizon, or time division, characterized by an interregional fauna. Use of the term in this significance would recognize not only biologic development, but also geologic events, for an interregional fauna can appear only in times of readjustment of biologic regions, of trangressions of the sea on the land, or of opening up connections between regions that before were separated. These are nature's periodic trial balances, during which the geologic columns in various regions, for a while divergent in biologic development and thus in stratigraphic classification, are brought into harmony.

A zone, in this sense, means a comparatively short time in which a certain characteristic, limited group of animals or plants lived—too short for any great faunal change, but long enough for this group to diffuse itself over a great area. To illustrate this let us take a well known example. It must have taken a long time for *Productus semireticulatus* to be dispersed through the seas of Australia, Eurasia, and America, for it is found in all those regions. But no stratigrapher would choose this species as a zone fossil, since it ranges from the Mountain Limestone into the Permian; often characteristic of a certain province during a given time, but of no one horizon everywhere. And during this long time the greater part of the accompanying faunas underwent enormous changes, until most of the genera, even, were new. During all these migrations *Productus semireticulatus* itself underwent modifications until it might be divided into a number of geographic species or varieties, and each of these into mutations or varieties in an upward-ranging genetic series. But accompanying *Productus semireticulatus* there are many species and genera that were short-lived and widely distributed, in some one region appearing as a link in a genetic series, but in some other region appearing sporadically or unheralded by local ancestors, and brought in by immigration

from the outside world. The appearance of such genera or species is an interregional event, and marks an episode in the dynamic history of the earth. Zones are thus not a figment of the stratigrapher's imagination, but are based on geologic events of far-reaching importance, in comparison with which the local shiftings of lithologic facies are insignificant.

Ancient faunal geography.—One of the first things that attracted the attention of naturalists engaged in the study of geographic zoölogy was that animals are not now distributed strictly according to climate, or other physical conditions. Edward Forbes early reached the conclusion that the ancient marine faunal provinces and regions by no means corresponded with the present distribution, and that the present faunal relations could be explained only by study of past geologic changes in the distribution of land and water. The various marine provinces were grouped by S. P. Woodward[1] in great regions: "The tropical and subtropical provinces might naturally be grouped in three principal divisions, viz., the Atlantic, the Indo-Pacific, and the West-American—divisions which are bounded by meridians of longitude, not parallels of latitude. The Arctic province is comparatively small and exceptional; and the three most southern faunas of America, Africa, and Australia differ extremly, but not on account of climate."

What is true of faunal geography today was true of it in the past. While certain faunas, such as the Silurian, have been very widely distributed, on account of the existence then of wide expanses of shallow marginal and epicontinental seas, there were no such things as universal faunas, even in the most remote geologic time. There have always been barriers of continent and ocean, and probably too of climate, ever since life existed on the earth. Only the deep sea faunas could be universal if oceanic basins had been stable; but such faunas are not universal now, nor have they remained unchanged in time.

Many years ago Barrande[2] showed that the Cambrian

[1] Manual of the Mollusca, 1856, p. 353.

[2] Système Silurien du Centre de la Bohême.

deposits known at that time could be grouped in well-defined geographic provinces; it is true that there was a great similarity of animal life in the various regions, but this by no means amounted to identity. Most genera had a wider range then than in later formations, but community of species was as rare in the Cambrian as in the later Mesozoic. Walcott has divided the Cambrian into three great divisions, each named after the most characteristic genus in it: the lower, or *Olenellus* zone; the middle, or *Paradoxides* zone; and the upper, or *Olenus* zone. No one of these had a universal fauna, although certain subdivisions can be traced through several provinces and even regions, and thus deserve the designation "zone," as Oppel used the word. It is noteworthy, too, that these times of interregional distribution come at periods of transgression of the seas on the land, so that a connection between these two phenomena may justly be inferred.

The work of Barrande, James Hall, and Murchison has shown that the Silurian strata and their fossils are as widely distributed as the Cambrian. But during Lower Silurian time the faunas of the American and the European region seem to have been largely endemic. The Trenton sea probably covered the greater part of North America, but only that in the northeastern part of the region shows much relationship to the European. During the Upper Silurian there was considerable readjustment and shrinkage of the sea, and as a consequence of this the Niagara limestone may justly be considered as an interregional zone, although the exact period of the migration cannot be determined.

During the Lower and Middle Devonian the division into regions that had existed in the Silurian still held sway, for it has been shown by H. S. Williams that there was a North-South American and a Eurasian region. But with the beginning of the Upper Devonian the connections had changed so that the grouping was Eurasian-North American, and South American-South African. This change shows itself in North America at the base of the Upper Devonian, where with the *Cuboides* zone

of the Tully limestone there was ushered in a fauna that could not possibly have been developed out of its local predecessors in the Hamilton beds, but whose affinities are with the Upper Devonian of Europe and Asia; in this latter region the *Cuboides* fauna is genetically connected with its predecessors of the Lower and Middle Devonian. In this invasion of the American waters by the *Cuboides* fauna, we have an undoubted zone, the first great interregional migration that can be traced in the history of the earth. But, as has been shown by Professor Williams,[1] this means something more than a mere migration, it means a complete readjustment of the faunal geography of the time. The invasion thus begun was kept up during the succeeding *Intumescens* zone, when Eurasian cephalopods began to make their way from the northwest into the New York[2] province. In these two zones we have divisions that are stratigraphically as well as faunally homotaxial with European beds, that is, they are virtually contemporaneous with them.

The Lower Carboniferous is well known to have beeen a time of extensive encroachment of the sea on the land, in Europe and America, but the boundaries of the sea were not uniform during the various stages of this age.[3] Oscillations within the regions were common, and sometimes they were great enough to allow the influx of an exotic fauna, such as those of the Kinderhook horizon, and of the St. Louis division. On a smaller scale the inter-provincial migrations, or colonies, are known at several different horizons of the Lower Carboniferous, occurring always at a time of expansion of the sea, as in the Burlington division of the Osage, and the St. Louis beds.[4]

The Upper Carboniferous, on the other hand, in the Mississippi valley region of the United States, and in western Europe

[1] The Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer. Vol. I, 1890.

[2] J. M. CLARKE: Naples Fauna, Sixteenth Ann. Rep. New York State Geol., 1898.

[3] S. WELLER: JOUR. GEOL., Vol. VI, 1898, Classification of the Mississippian Series.

[4] H. S. WILLIAMS: Amer. Jour. Sci., Vol. XLIV, 1895, On the Recurrence of Devonian Fossils in Strata of Carboniferous age.

was a time of encroachment of the land on the sea, and only occasionally, when the sea had temporarily reclaimed its own, are marine faunas found in this formation. But when these occur, they are often extra-provincial, and occasionally extra-regional in origin, and thus give a secure basis for correlation with those regions where marine conditions still prevailed. Such a state of affairs existed in western North America and in eastern Europe during the time of the Coal Measures; in these regions the sea transgressed over the land areas, and allowed the marine faunas to become widely distributed. By intermittent subsidence of the low-lying coal swamps an intercalation of marine with freshwater deposits took place, allowing accurate correlation between the two facies.[1] And occasionally these oscillations have been something more than local events, for they have brought in exotic faunas, as in the case of the belated immigration of *Pronorites cyclolobus* and *Conocardium aliforme* in the Lower Coal Measures of America, or the appearance of *Gastrioceras* and *Paralegoceras* in the European waters long after they had appeared in America. The greatest of these disturbances was the Appalachian revolution, which at the beginning of Permian time raised finally above water the continental borders of the old Appalachian land mass, and left only a comparatively small basin for the Permian sea. This rising of the Mississippi valley region was undoubtedly accompanied by sinking elsewhere, for a very similar exotic fauna appeared simultaneously in the American, the European, and the Asiatic region, and mingled with the preëxisting local faunas, giving one of the most distinctive paleontologic zones yet known,

During the Lower Trias the Arctic, the American, and the Oriental regions had closely allied faunas, and might be grouped together in contrast with the Mediterranean. At this time of transgression and readjustment of geographic boundaries we have the widely distributed fauna of the *Meekoceras* zone, distinctly recognizable in India, Siberia, and western America.

[1] J. P. SMITH : JOUR. GEOL., Vol. II, No. 6, 1894, The Metamorphic Series of Shasta County, California.

The Middle Triassic faunas seem to have been largely endemic, because the waters of that time were stable; thus there are no horizons that are directly comparable in distant lands. But again the Upper Trias ushered in a period of transgression and invasion, and the faunal zone of *Tropites subbullatus* appeared simultaneously in the Mediterranean region, in the Himalayas, and in California, with many genera and species common to these countries, exotic in all, and with no previous record to show their origin.

The geographic provinces of Jurassic time have been grouped by Neumayr[1] in two great regions, the Boreal and the Central Mediterranean, and further he has traced out the distribution of climatic zones of that time in the Boreal type, the North Temperate type, the Alpine or Equatorial, and the South Temperate. The western American province belonged to the Central-Mediterranean region and to the North Temperate climatic zone during Lower and Middle Jura, but with the beginning of the Upper Jurassic a great change took place in physical and faunal geography that connected the western American province for a time with the Boreal region. As a consequence of this the faunal zone of *Cardioceras alternans* and *Aucella pallasi* may be traced through Russia, Alaska, and California.[2] The disturbance that caused this invasion may easily be traced in the transgression eastward of the sea on the land that began in northern Europe already in Middle Jurassic, bringing down from the northwest a cold current that permitted the Boreal fauna to make its way into temperate latitudes on the western coast of North America.

The study of the distribution of fossil faunas as influenced by climate was begun by Ferdinand Roemer,[3] who recognized the fact that the Cretaceous of western Europe was similar to that of the Atlantic region in America, and that the faunas of southern Europe, northern Africa, Texas, and Mexico had much in

[1] Denkschr. K. Akad. Wiss. Wien, 1883. Klimatische Zonen während Jura und Kreidezeit.

[2] J. P. SMITH: JOUR. GEOL., Vol. III, 1895, Mesozoic Changes in the Faunal Geography of California.

[3] Kreidebildungen von Texas, 1852.

common. These differences Roemer ascribed to climate, noting that then, as now, the isothermal lines came much further south in eastern America than in Europe.

It has been shown that at the beginning of Cretaceous time the faunal relations of the west coast of North America were still with the Boreal region, as in the Upper Jurassic. But this did not last long, for even before the end of the Knoxville epoch this fauna had died out, and was replaced by immigrants from another region. At first there were only a few stragglers, but soon the rich fauna of the Horsetown stage or Gault made its appearance, of a type precisely like that of southern India, and eastern Africa. A similar association of genera and species is also known in the European region, where it seems to have been endemic, and from which it probably reached the rest of the world by migration. This incursion of exotic faunas marks the last great period of readjustment of the geologic column in various parts of the world, and is therefore of the utmost importance in correlation. The kinship of the western American faunas to the Indian was stronger than that to the eastern American almost until the end of the Cretaceous, when a similarity to the interior province began to show itself. This change culminated in Eocene time, in the zone of *Venericardia planicosta*, when the barrier between the western and the interior Cretaceous provinces was temporarily removed, and through the Atlantic there was direct connection with the European waters. This is the last interregional zone, but it marked an era of retrogression of the sea, rather than of transgression, and since that time the marine provinces and regions correspond closely with the existing boundaries of temperature and shore lines.

Dispersion of marine animals in past and present.—Theoretically, pelagic faunas would be the best means of correlating distant regions; but in all probability we have no fossil pelagic faunas. J. Walther suggests that in the widely dispersed species of Mesozoic ammonites we have virtually a preservation of pelagic animals, or at least that their shells floated after death, and were distributed all over the earth by marine currents. This

sounds plausible, viewed in the light of what we know of the distribution of *Spirula.* But the living Pearly Nautilus is not distributed by currents away from the region of its present habitat, and in studying fossil faunas we find that the cephalopods had little wider distribution than brachiopods and pelecypods, animals usually fixed in station during most of their life, and able to migrate only during the larval stage. Another argument against the current-distribution hypothesis has been brought up by Dr. A. Tornquist, that the fossil ammonites of Jurassic and Cretaceous age are distributed approximately according to climatic zones.

The geologic record has been kept by the inhabitants of submerged continental or island shelves, and their dispersion cannot have been accidental or individual, but was faunal. The means and the reason for this migration are furnished by changes in physical geography. Any rising or sinking of shore lines would drive the inhabitants from their dwelling places ; any newly opened connections between regions that before were separated would cause an intermingling of different faunas. An example of this is going on before our eyes today ; the Red Sea and the Mediterranean have faunas as distinct as if they occurred on opposite sides of the world, but since the opening of the Suez Canal, intermigration has already begun, and in this present age will be recorded an inter-regional invasion comparable with those that took place in remote geologic time. And no doubt to some future geologist this record will be just as clear as those we have of similar changes in the past. Each great change in the outlines of continents must also have caused great changes in the direction of marine currents. Thus in the great subsidence of land in northern Eurasia that caused the transgression of the Upper Jurrasic sea must have opened the way for the cold current that came from the northwest along the Pacific shore of North America, bringing a Boreal fauna into temperate latitudes. Something similar to this would happen if, at some future time, the old dismembered Antillean continent were raised to its former position; the Gulf Stream could not enter the warm waters

of the Carribean, would be deflected, and the waters of the northwestern coast of Europe would be chilled.

The horizons of America that represent periods of instability of shore lines are the very ones that contain the remains of exotic faunas, such as those of the *Cuboides* zone, the *Intumescens* zone, the Chouteau limestone, the St. Louis beds, or the shifting zones of the Coal Measures. These migrations must all have been faunal rather than individual, and can have been due only to physical agencies acting slowly and on a large scale. No extraordinary catastrophies need be appealed to as an explanation of this, for similar phenomena are always going on before our eyes, in the slow but ceaseless rising of some shores and sinking of others.

Land masses present an insuperable barrier to marine animals; but if the bodies of land are short, and do not reach into polar waters, animals can easily pass around the ends. Thus the molluscan fauna of the Mediterranean does not differ greatly from that of the English waters, because in the passage around the peninsula of Spain, animals remain in temperate waters and under nearly the same conditions. East and west land masses would, therefore, not be effectual barriers, since they would not be so likely to extend into frigid waters nor into very great differences of temperature. An example of this is the similarity of marine faunas on the east and the west coast of Australia.

On the other hand, the Isthmus of Panama separates two faunas absolutely distinct from each other, although in the same latitude, and under the same climatic conditions. Also the Isthmus of Suez separates two totally distinct faunas, but these belong to different regions and even to different climatic zones, brought near together by the narrow strip of the Red Sea. A similar case is known in the Jurassic formation, where the fauna of western Europe stands sharply contrasted with that of Russia; even the characteristic genera are distinct, and this too in latitudes not very different. These two types represent two seas of different climatic zones, separated by a strip of land during the later portion of Jurassic time.

That climatic zones alone are to-day partial barriers to migrants along the coast is shown by the difference in faunas living in northern and in southern latitudes on north-south shores. We would expect cold water species to be able to cross climatic zones more easily than those adapted to warm water. But we know of no cases where equatorial faunas have passed through arctic regions, and even passages from tropical into temperate waters must have been exceedingly difficult, for a fall of a few degrees below the temperature favorable to life must be a great deal more destructive than a rise of many degrees. At present we have no means of testing this statement, but facts brought to light by geology confirm it. The Jura of western Europe and of the Argentine Republic have practically the same fauna, which, in reaching one of these regions from the other, must have passed from temperate waters through tropical, and into temperate seas again. The genera *Lytoceras* and *Phylloceras* are common in the Neocomian beds of southern Europe; but although these waters were undoubtedly connected with those of northern Europe, those genera are lacking in the latter region. Also in the lower part of the Californian Knoxville beds, the above mentioned genera are unknown, and come in only higher up where the first members of the tropical Indian fauna began to appear.

By far the greater part of marine animals live near the shore and are unable to exist under other conditions. To these an abyssal sea is as impassable a barrier as a continent. The marine faunas of the southern ends of Africa, South America, and Australia are in approximately the same climatic conditions, but although they are connected by open seas, they are as different as if they were in totally disconnected basins. But an east-west sea affords good opportunity for passage from one side to the other by slow passage along the margin. The present fauna of the Mediterranean is good evidence of this, the animals of the European shores not differing appreciably from those of the African. The Mesozoic faunas of the ancient Central-Mediterranean sea owe their great distribution to this fact, for nearly the

same conditions existed then as in the present Mediterranean, except that the extent was vastly greater.

And even on opposite sides of great north and south oceans there are usually many species in common; the Atlantic shore American fauna has many European species, and the Pacific shore harbors some from Asiatic waters. Their passage was affected in most cases along continental borders that have since been obliterated by subsidence and erosion. We have an abundance of geologic and biologic evidence that just such changes have taken place in comparatively recent time, for example, the dismemberment of the old Antillean continent since Tertiary time. Also in the Indian Ocean there existed a continent in late Paleozoic and early Mesozoic time, connecting Australia with Asia; and Wallace[1] has shown that even since the Tertiary, Australia has been connected with many of the now separated islands of the Indian Ocean, although cut off even then from Asia.

The occurrence of identical or very closely related species in widely separated localities is good evidence of migration from one of these localities to the other, or from a third region to both. In many cases faunas even appear unheralded by local ancestors; these are exotic, having been brought in by migration from outside regions. In the chapter on paleontologic zones many of these exotic faunas have been enumerated, and the general statement made that their appearance invariably coincides with a time of shifting of the boundaries of land and sea, and consequent opening of new connections.

Colonies.— It is often noticed that species or faunas are intermittent in occurrence, especially when the character of the sediments is shifting. When sands are being deposited in shallow waters certain animals find their favorite habitat there, and when subsidence cuts off the clastic sediments and the waters become clear, other animals hold sway. Such faunal changes are due to the facies of sedimentation, but both sorts lived in the same

[1] Geographical Distribution of Animals, Vol. II, The Australian Region, pp. 387–485.

province and near together. But intermittence of occurrence is occasionally noted when it cannot be due to difference of facies. Just such a case is the reappearance of a Chouteau fauna in the Osage horizon of Missouri,[1] or the reappearance of Devonian types in the St. Louis beds at a number of places in the United States. In the Jura of northern Europe, according to Neumayr,[2] the genera *Lytoceras* and *Phylloceras* appear only sporadically, being lacking in sixteen zones; and even the known species there do not belong to a genetic series. But in southern Europe these genera appear plentifully in all the zones, and seem to represent genetic series. Their migration northward at several successive periods is thus clearly established. In these same beds *Amaltheus* also appears intermittently, but no region is yet known where *Amaltheus* developed continuously. Among the Jurassic ammonites of northern Europe there are a number of other cryptogenic types, many of which coincide with the *Amaltheidae* in their appearance, and thus probably came from the same region.

Today, when the struggle for existence becomes too severe for a species it disappears. In geologic history, too, a species has a certain length of life and dies out, never to reappear. This has given rise to the theory that species, like individuals, have a limited life, and that in time they reach a stage of development where they can go no further, and then of necessity die out. This would all be very well if species dropped out one at a time and contemporaneously all over the earth, but in reality they come and go by faunas. A study of the successive fossil faunas of the Pacific coast region has shown that while there may be a nearly perfect stratigraphic series, the faunal succession is broken, so that each fauna appears unheralded, in a way that would have delighted the heart of Cuvier. But we often find the forerunners of these unheralded faunas in older beds in other regions; this gives the rational explanation of the phenomenon,

[1] C. R. KEYS: Amer. Jour. Sci., Dec. 1892, p. 447.

[2] Jahrbuch K. K. Geol. Reichsanstalt, Wien. Bd. 28, 1878. Ueber unvermittelt auftretende Cephalopodentypen in Jura Mittel-Europas.

migration due to the removal of barriers.[1] It would seem, then, that changes in physical geography have been the chief cause, not only of migration, but also of extinction of faunas; and this becomes all the more probable when we reflect that species have not been extinguished contemporaneously over the earth.

Remarkable cases of survivals of types have long been known, as of *Trigonia* in the Australian waters, and of *Pholadomya* in the Antilles. Survivals of faunas, too, are continually coming to light. A number of species that on the west coast of the United States are known only as fossils in Pliocene and Quaternary strata, are still living elsewhere. Dall[2] has shown that a large proportion of the Pliocene and even Miocene invertebrates of the southeastern states are still found living in the archibenthal region off the present coast. Similarly, it has been shown by Walcott[3] that in the Great Basin Carboniferous province many Devonian types persisted long after they had become extinct elsewhere, and this has been used by H. S. Williams[4] to explain the reappearance in the Mississippi valley St. Louis beds of a fauna previously thought to have been extinct since the very beginning of Carboniferous times.

Dr. David Brauns[5] cites from the late Pliocene or early Pleistocene of Japan a large number of species that are still flourishing on the western coast of America, and some are found living there that in western America are known only as fossils. Thus in the future some confusion might originate by correlating these beds with those now forming.

It is well known that during the Upper Carboniferous there flourished in India, South Africa, and Australia the *Glossopteris* flora, a type that in other regions was characteristic of Mesozoic instead of Paleozoic beds. Waagen[6] has suggested that the

[1] J. P. SMITH: JOUR. GEOL. Vol. III, 1895. Mesozoic Changes in the Faunal Geography of California.

[2] Bull. Mus. Comp. Zoöl., Vol. XII, No. 6, p. 186.

[3] Mon. VIII, U. S. Geol. Survey.

[4] Amer. Jour. Sci. III Ser., Vol. XLIX, pp. 94–101.

[5] Mem. Science Dept. Univ. of Tokio, No. 4, 1881, p. 77.

[6] Pal. Indica. Salt Range Fossils. Geological Results, p. 240.

glaciation in this region near the beginning of Permian time killed off the Paleozoic flora and allowed the *Glossopteris* flora to get a foothold earlier than was the case where there was no glaciation. Such phenomena approach the nature of catastrophes, and show that Cuvier's doctrine was not altogether wrong after all, and he probably had something like this in mind, although not formulated. These facts, too, show that the principles on which Barrande's[1] doctrine of "colonies" was founded were right, even though it has since been found that the particular cases on which he based his colonies were only younger rocks carried into the midst of older beds by dislocations. Barrande's idea seems to have been that in certain separated basins a new type of life would be introduced before it appeared elsewhere, and that by changes in physical geography these precursor faunas would be intercalated with those of older type. The modern doctrine of colonies, on the other hand, is that older faunas have often been preserved in places where no great changes have taken place in the conditions necessary for their life, and that these older surviving faunas have been mingled as anachronisms with the younger through immigration made possible by the removal of barriers, or changes in the direction of ocean currents.

Synchronism vs. homotaxis.—Forms are said to be heterochronous when they occur at different horizons, in different regions. Now it is possible that the same species seldom occurs at exactly the same time in two widely separated places; it must originate at the one and migrate toward the other, or migrate to both from a third place. This would take time, and it is supposable that the species might be entirely extinct at the point of origin before it reaches its second habitat, or become so greatly modified on its journey as to require a new name, or a number of new names. A case in point is the migration and development of *Ceratites nodosus* in the middle Trias of Germany. In the North-German basin this species is exceedingly common in the Muschelkalk, and exceedingly variable, but the boldest species-maker has not yet dared

[1] Système Silur. du Centre de la Bohême, Vol. I, p. 73 et seq.

to split it up into a number of species, because there are transitions between all the varieties. Dr. A. Tornquist[1] has recently shown that *Ceratites nodosus* also occurs in the upper Muschelkalk of the southern Alps, and that there the varieties lack the transitions, and thus may be given names to mark this transformation. The immediate varieties never reached the Alpine province, or else the modification took place on the way. The zone of *Ceratites nodosus* is thus inter-provincial in extent.

A somewhat similar case is known in the distribution of certain living species of the genus *Purpura;* in the English waters *Purpura lapillus* is common and exceedingly variable, but no constancy can be traced in these variations, the influence of temperature, sea bottom, and food supply being so evident, and the transitions so gradual that no subdivision of the species is attempted. Some of these same varieties are found on the western coast of America, but without the transitions, and so they are called by a number of specific names, which, although they are given to forms locally distinct, can certainly be only synonyms of *Purpura lapillus*. At some not very distant time these forms migrated westward from the Atlantic waters, and either varied on the journey, or else the intermediate forms did not succeed in reaching the Pacific region.[2] Here is certainly an interregional migration where a species is still living in the waters where it originated.

The genus *Clymenia*, according to J. M. Clarke,[3] appears in the *Goniatites intumescens* zone in New York ; in Europe *Clymenia* is wholly unknown in the *Intumescens* fauna, but is the characteristic form of the next higher division of the Devonian, where the *Intumescens* fauna was already extinct. In North America *Pronorites cyclolobus* and *Conocardium aliforme* appear in the Lower Coal Measures, while they flourished in Europe in the zone of

[1] Zeitschrift d. Deutschen Geol. Gesell. Bd L. Heft 2, 1898, and Heft 4. 1898. Neuere Beiträge zur Geol. und Paläntol. der Umgebung von Recoaro and Schio (im Vicentin).

[2] A. H. Cooke, Mollusks, 1895, pp. 90 and 363.

[3] Am. Jour. Sci., Ser. 3, Vol. XLIII, p. 57.

Goniatites striatus of the Mountain Limestone. The genera *Gastrioceras* and *Paralegoceras* appeared in America in the zone of *Goniatites striatus*, while they are not known in Europe before the Coal Measures. But the accompanying faunas in these regions are, in the main, correlative, and so the heterochronous appearance can be detected.

In the Upper Trias, Karnic stage, of California *Halorites* occurs, although in both the Alps and the Himalayas it is characteristic of the higher Noric stage. Also in California *Trachyceras* and *Protrachyceras* occur in the zone of *Tropites subbullatus*, mingled in the same hand specimen with typical species of the *Subbullatus* fauna; in the Alps and in the Himalayas *Trachyceras* and *Protrachyceras* are older than the *Subbullatus* zone, and are never found in it.

Now, when we have fossil species or short lived genera common to two regions, are the strata of these regions to be considered as synchronous? Huxley[1] advanced the theory that migration from one region to another would consume so much time that a fauna might become extinct in one region before it reached the other, and that since we determine the age by these faunas, the time of deposition of strata assigned to the same geologic age might be very different. Thus a Silurian fauna might survive in one region, while a Devonian fauna flourished in a second, and a Carboniferous fauna might be beginning in a third region. But the fossiliferous beds are Silurian, or Devonian, or Carboniferous in the faunal sense. This relation Huxley called *homotaxy*, and most geologists have accepted without question the validity of the hypothesis.

Viewed in the light of modern distribution of fauna, there must be something in it. The present Australian fauna is often cited as an example of unreliability of the time scale when based on faunas, as a survival of Quaternary life at the present time; it certainly is peculiar, for the continent has been totally cut off from other regions since early Mesozoic time. This fauna, however, has not dropped behind; it has gone on specializing in

[1] Presidential address. Quart. Jour. Geol. Soc. London, 1862. Vol. XVIII.

TABLE OF INTERREGIONAL ZONES

		EUROPE	NORTH AMERICA	ASIA
TERTIARY	Pliocene			
TERTIARY	Miocene			
TERTIARY	Eocene	Zone of Venericardia planicosta	Atlantic Slope, Gulf Region California and Oregon	
CRETACEOUS	Upper	Zone of Hippurites	Texas and Mexico	
CRETACEOUS	Upper	Zone of Schloenbachia	West coast and Interior	India
CRETACEOUS	Lower	Zone of Acanthoceras mamillare	West Coast	India
CRETACEOUS	Lower	Zone of Aucella terebratuloides	California and Alaska	Siberia
JURASSIC	Upper	Zone of Cardioceras alternans	California	India and Siberia
JURASSIC	Middle			
JURASSIC	Lower	Zone of Arietites	Nevada and California	Japan and Island of Rotti in the Indian Ocean
TRIASSIC	Upper	Zone of Tropites subbullatus	California	India
TRIASSIC	Middle	Zone of Ceratites and Beyrichites	Nevada	India and Siberia
TRIASSIC	Lower		Zone of Meekoceras boreale in California and Idaho	Siberia and India
CARBONIFEROUS	Permian	Zone of Medlicottia in Sicily and Russia	Texas	India and China
CARBONIFEROUS	Coal Measures	Zone of Gastrioceras marianum	Mississippi Valley and Texas	? Beds of Lo Ping China
CARBONIFEROUS	Coal Measures	Zone of Gastrioceras listeri	Mississippi Valley	
CARBONIFEROUS	Coal Measures	Zone of Glyphioceras beyrichianum	Arctic America	Sumatra ?
CARBONIFEROUS	Lower Carboniferous	Zone of Goniatites striatus	Mississippi Valley and Texas	
CARBONIFEROUS	Lower Carboniferous	Zone of Productus giganteus in Russia and Belgium	California	Siberia and China
CARBONIFEROUS	Lower Carboniferous	Zone of Aganides rotatorius	Mississippi Valley	
DEVONIAN	Upper	Zone of Manticoceras intumescens	New York	Siberia ?
DEVONIAN	Upper	Zone of Rhynchonella cuboides	New York	Siberia
DEVONIAN	Middle			
DEVONIAN	Lower			
SILURIAN	Upper	Zone of Calymmene blumenbachi	Mississippi Valley and New York	
SILURIAN	Lower			
CAMBRIAN	Olenidian	Olenus fauna	Canada	
CAMBRIAN	Paradoxidian	Paradoxides fauna	United States and Canada	
CAMBRIAN	Olenellidian	Olenellus fauna	United States and Canada	

its own lines, and in all the geologic ages to come will never reach the development of life as we know it elsewhere in the Era of Man.

But is the marine fauna on the Australian shores markedly different from that in other parts of the Indian Ocean, and has that of the Indian Ocean no near relationships with the outside world? There are faunal provinces in these, with local characteristics, but with gradual transition from one province to another, and from one region to another through adjacent provinces. Thus the Australian waters show a gradual transition in fauna to the China Sea, and that to the Japanese marginal fauna, which, in turn, show many species in common with the west American region.

If, then, the modern Pacific and Indian Ocean marginal faunas were fossilized it would be no great task to correlate them, although the western coast of America might not show a single species in common with Australia. The laws that govern the distribution and intergradation of marine faunas are the same now as they have always been. All stratigraphic classification and all paleontologic correlation are based ultimately on fossil marine faunas.

The reality of correlation.—The geologic succession of faunas has some irregularities and anomalies, as shown above, but the displacements of the time scale are too slight and the uniformity in various separated regions too great to lay much stress on homotaxis as opposed to synchronism. While homotaxial strata are not necessarily synchronous in years nor in centuries, the cases cited above show that they often are actually contemporaneous. But even if they were not, years and centuries count little as compared with the time back to the Quaternary, and still less with the great stretches of time in the Paleozoic. And if a Silurian fauna still persists beyond its time by reason of local favoring conditions, it is merely a transient exception, for interregional migration soon readjusts the faunal scale in harmony with the time scale. The survivals of species or faunas are the exception rather than the rule, and such anachronisms can be detected in the past as well as now.

If there had ever been any great displacement of the faunal scale from the time scale, this would have been cumulative, and eventually the paleontologic column of America would have been out of harmony with that of Europe. But the successive faunas from Lower Cambrian to Pleistocene are in perfect accord in all the regions of Europe, Asia, Africa, America, and Australia; there are constantly recurring small displacements due to temporary isolation, and constantly recurring readjustment due to reopened or newly-formed connections, giving interregional correlative faunal zones through migration. These zones may be, and often are, actually synchronous. The periods of endemic development may be homotaxial, but the zones of readjustment are correlative in the strictest sense.

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